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No. 107

(6) QUANTITATIVE MEASUREMENTS OF RADAR ECHOES FROM AIRCRAFT
VII. B-36 AND F-86 SPECTRUMS.

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RADIO DIVISION I

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QUANTITATIVE MEASUREMENTS OF RADAR ECHOES FROM AIRCRAFT
VII. B-36 AND F-86 SPECTRUMS

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15 January 1953

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ABSTRACT

Spectral analyses have been made of the radar echoes of B-36 and F-86 aircraft for aspects near head-on, broadside, and tailward. In the B-36 echo there are discrete frequency components arising from propeller modulation, except at broadside aspect, where the relative effect of the propellers is minimum. The F-86 spectrums are similar for all three radar frequencies, the spectrums tending to be shifted to higher fluctuation frequencies as radar frequency increases.

PROBLEM STATUS

This is an interim report on the problem; work continues.

AUTHORIZATION

NRL Problem R11-17

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INTRODUCTION

In six previous reports (1) - (6) results were given of the measurements of the radar echo characteristics of aircraft, made by the Naval Research Laboratory for the Department of the Air Force. In particular, the measurements of the B-36 and F-86 have been completely reported except for analyses of fluctuation rates of their radar echoes.

The present report contains spectral analyses of the B-36 and F-86 echoes for aspects near head-on, broadside, and tailward, and forms the final report on these two aircraft.

The spectrums were obtained by transferring five seconds of pulse-to-pulse data to a magnetic tape, which was then made into a loop and scanned repeatedly by a pickup head feeding a General Radio wave analyzer. The wave analyzer was swept slowly in frequency, and its output was passed through a smoothing circuit, and then to a Sanborn recorder (7).

Detailed Procedure.

To obtain a spectrum, the following steps were performed in sequence:

1. Five seconds (600 pulses) of pulse-to-pulse deflections were read consecutively to the nearest db.

2. The db levels were converted to (video) voltage levels.

3. The 600 voltage readings were plotted linearly against time and the consecutive points were connected by straight line segments. Samples of the resulting plots are shown in Fig. 1.

4. The plot was placed in the input mechanism of a transcriber, the "curve" on the plot was followed manually with a stylus, and the voltage corresponding to the stylus displacement was entered on magnetic tape as frequency modulation of a carrier frequency.

5. The resulting magnetic tape was made into a loop and used as input to the spectrum analyzer.

The resulting spectrum emerged from this processing as a continuous curve on a Sanborn Recorder chart. For the B-36 and F-86, these spectrums are found in Figs. 2 through 6. The magnetic tape loops were about 34 inches in circumference, and were passed under the reading head of the spectrum analyzer at 30 inches per second. A complete sweep of the wave analyzer took about $6\frac{1}{2}$ minutes.

Properties of the Spectrum Analyzer Output.

Ideally, the output of the spectrum analyzer would give the spectral density of the frequency components contained in the input data. The spectral density is denoted by a quantity, $A(f)$, equivalent to the ratio between the r-m-s voltage reading of a hypothetical a-c voltmeter measuring the input voltage after it is filtered by a square band-pass filter of bandwidth one cycle, and the reading V_o of a d-c voltmeter which measures the input voltage. The input voltage is the video voltage corresponding to the measured radar echo. The units of $A(f)$ are (cycles per second)$^{-\frac{1}{2}}$.

For each loop of magnetic tape, the average voltage V_o was measured by passing the voltage picked off the tape loop through what is essentially a low-pass filter followed by a d-c voltmeter. The response of the analyzer was then calibrated by using as input a sinusoidal voltage of known amplitude. The resulting calibration "pulses" are shown at the right hand ends of Figs. 2 - 6. (There is often a switching transient at the left of the calibration pulse.) From the shape of these curves, one obtains the resolving power of the spectrum analyzer for the input data. On the frequency scale of the radar data, the two ordinates at 70.7% of peak deflection are separated by about 1.25 cps. Thus the spectrum analyzer resolves two discrete frequency components in the input data only if the components are separated in frequency by as much as 1.25 cps. Furthermore, if the input data have a continuous spectrum plus a few widely separated discrete frequencies, the output of the spectrum analyzer will show peaks at the discrete frequencies; the peaks will have the shape of the calibration "pulse", but will be raised above the zero ordinate by an amount corresponding to the local level of the continuous part of the spectrum. The head-on B-36 spectrums of Fig. 2 are of this nature.

There are several qualifications to this interpretation of the plotted spectrum. First, in order to keep the time required to sweep

the analyzer through the frequency range at a reasonable value, a compromise was effected in choosing the time constant of the smoothing circuit following the wave analyzer. This results in a small variation of the output in synchronism with the loop rotation rate, which produces a rapid scintillation of the trace. Formally, the correct value of A(f) would be found by taking an r-m-s average of the scintillations, but the curve passed centrally through the scintillations is sufficiently close for practical purposes.

Second, some of the spectrums would seem to give A(f) for frequencies above 60 cps. Since the input data were formed essentially by smoothing discrete voltage readings separated in time by 1/120 sec., the outputs contain no real information at frequencies above 60 cycles at most.

Third, the output of the analyzer falls off at the low end of the frequency spectrum. The ratio of the recorded value of A(f) to the true value is less than unity for sufficiently low frequencies. This ratio (the relative response of the analyzer) is plotted against frequency in Fig. 7, from which one sees that the A(f) plotted by the spectrum analyzer is significantly low for frequencies below about 3 cps. This is no serious restriction, however. For, in the loop of five seconds of radar video voltage, there are less than 15 complete cycles of any frequency component of frequency less than 3 cps; thus 3 cps is approximately the lowest frequency for which a spectral analysis of only 5 sec. of data is valid.

The fourth qualification pertains to the discrete nature of the input data. The fluctuating radar echo was sampled 120 times per second. If a 120 cps component is found in the echo, then the samples might have been selected from peaks or minimums of this component, depending on the relative phase. In either case, the net effect would appear in the record as a d-c voltage. Further, if a 130 cps component were present in the original echo, a 10 cps component would appear in the corresponding voltage vs. time plot similar to those of Fig. 1. For, of a 130 cps component, the radar samples a series of positive voltage swings, then a series of negative voltage swings, repeating this succession of samplings with period 0.1 sec. The same apparent 10 cps "beat" frequency will be found in the voltage vs. time plot for a 110 cps component in the echo. Thus, components in the radar echo commensurate with the 120 cps radar sampling rate or its harmonics not only cause low beat frequencies to appear on the voltage-time plot, but also there is an ambiguity in interpretation of a given frequency in the spectrum: a frequency of f cps in the spectrum

could be caused by either a frequency $(120\,n \pm f)$ cps in the radar echo, where n is an integer, or by a frequency f.

Discussion of the Spectrums.

Broadly speaking, the F-86 spectrums for a given aspect are similar for all three radar frequencies, the spectrum tending to be shifted to higher fluctuation frequencies and to be compressed as radar frequency increases. This is in rough accord with the principle that the radar echo from a large object such as the F-86 is composed of contributions from many parts of the object. As the aspect of the object changes, the relative phases of the several component echoes change at rates proportional to the radar frequency, so that the rate at which the total echo fluctuates is proportional to radar frequency.

Except at 16 cps on the X-band spectrum of Fig. 4, the F-86 spectrums contain no spikes having the shape of the calibration pulses. Thus, in the analyzed samples of F-86 radar echoes, there were, in the main, no significant discrete frequency components.

On the other hand, the available B-36 spectrums show discrete frequency spikes, especially near head-on, (Fig. 2) and toward the tail (Fig. 3, lower spectrum). In Fig. 2, the dominant S-band frequency component is at 12 cps; the corresponding spike on the L-band spectrum is also at 12 cps. Spikes are found on both spectrums also at frequencies 16, 26, 32, and 40 cps. As the location of these spikes is independent of radar frequency, they must be explained as beat frequencies arising from the chopping and modulating effects of the six three-bladed B-36 propellers, and the 120 cps pulse repetition frequency of both radars. Given a uniform propeller revolution rate of 2550 rpm at the cruising speed of the B-36, a three-bladed propeller would produce a modulation in the radar echo at frequency 127.5 cps, and at harmonics of this frequency. For the B-36 echo in a radar having a 120 cps pulse repetition frequency, the fundamental beat frequency would then be 7.5 cps. Reasoning backwards, a 12 cps beat frequency would correspond to a 132 cps propeller modulation frequency, or to the propellers' revolving at 2640 rpm. This appears to be a reasonable figure. A vast number of discrete beat frequencies are theoretically possible if the propellers revolve at different rates.

For the broadside view of the B-36, the spectrum at the top of Fig. 3 shows a bare suggestion of a 12 cps component; here the propellers are viewed edgewise by the radars and the echo from the

fuselage is relatively strong, so that little propeller modulation is to be expected. (The L-band echo was partially saturated at broadside, so that A(f) in this spectrum is inaccurate.) For the tailward view of the B-36, the propellers again influence the echo. The corresponding modulation seems to show up in the tailward spectrum at the bottom of Fig. 3 as a 7 cps beat frequency. This beat frequency corresponds well with a propeller revolution rate of 2540 rpm. The apparent difference between the 7 cps beat frequency of this spectrum and the 12 cps frequency of Fig. 2 probably arises from a real difference in propeller revolution rates prevalent during the two corresponding B-36 runs.

One further comment should be made on the spikes, which have been interpreted as representing the presence of discrete frequencies. For the B-36, these spikes show relatively little scintillation at their tops. This means that the corresponding discrete frequency was found in all portions of the five-second sample. For if the discrete frequency were found on the record in the first $2\frac{1}{2}$ sec., but not in the second $2\frac{1}{2}$, the corresponding spike would scintillate at the top, owing to the fast response of the recorder. Thus the scintillations on the spike at 16 cps on the X-band F-86 spectrum of Fig. 4 suggest that the corresponding 16 cps component is found predominantly in one portion of the five seconds under analysis.

SUMMARY

Spectral analyses have been made of the radar echoes of B-36 and F-86 aircraft for aspects near head-on, broadside, and tailward. In the B-36 echo there are discrete frequency components arising from propeller modulation, except at broadside aspect, where the relative effect of the propellers is minimum.

The F-86 spectrums are mutually similar for all three radar frequencies, the spectrums tending to be shifted to higher fluctuation frequencies as radar frequency increases.

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(1) C-3460-73A/50 Quantitative Measurements of Radar Echoes from Aircraft. I. B-36, B-45, F-51 and F-86 - 24 October 1950.

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(3) C-3460-94A/51 Quantitative Measurements of Radar Echoes from Aircraft. III. B-36 Amplitude Distributions and Aspect Dependence - 19 June 1951.

(4) C-3460-138A/51 Quantitative Measurements of Radar Echoes from Aircraft. IV. F-86 Amplitude Distributions and Aspect Dependence, NRL Letter Report dated 5 September 1951.

(5) C-3460-132A/52 Quantitative Measurements of Radar Echoes from Aircraft. V. Correction of X-Band Values, NRL Letter Report dated 24 October 1952.

(6) C-3460-143A/52 Quantitative Measurements of Radar Echoes from Aircraft. VI. Corrected F-86 Amplitude Distributions and Aspect Dependence, NRL Letter Report dated 15 December 1952.

(7) A detailed report of the spectrum analyzer and associated apparatus is in preparation by J. E. Meade.

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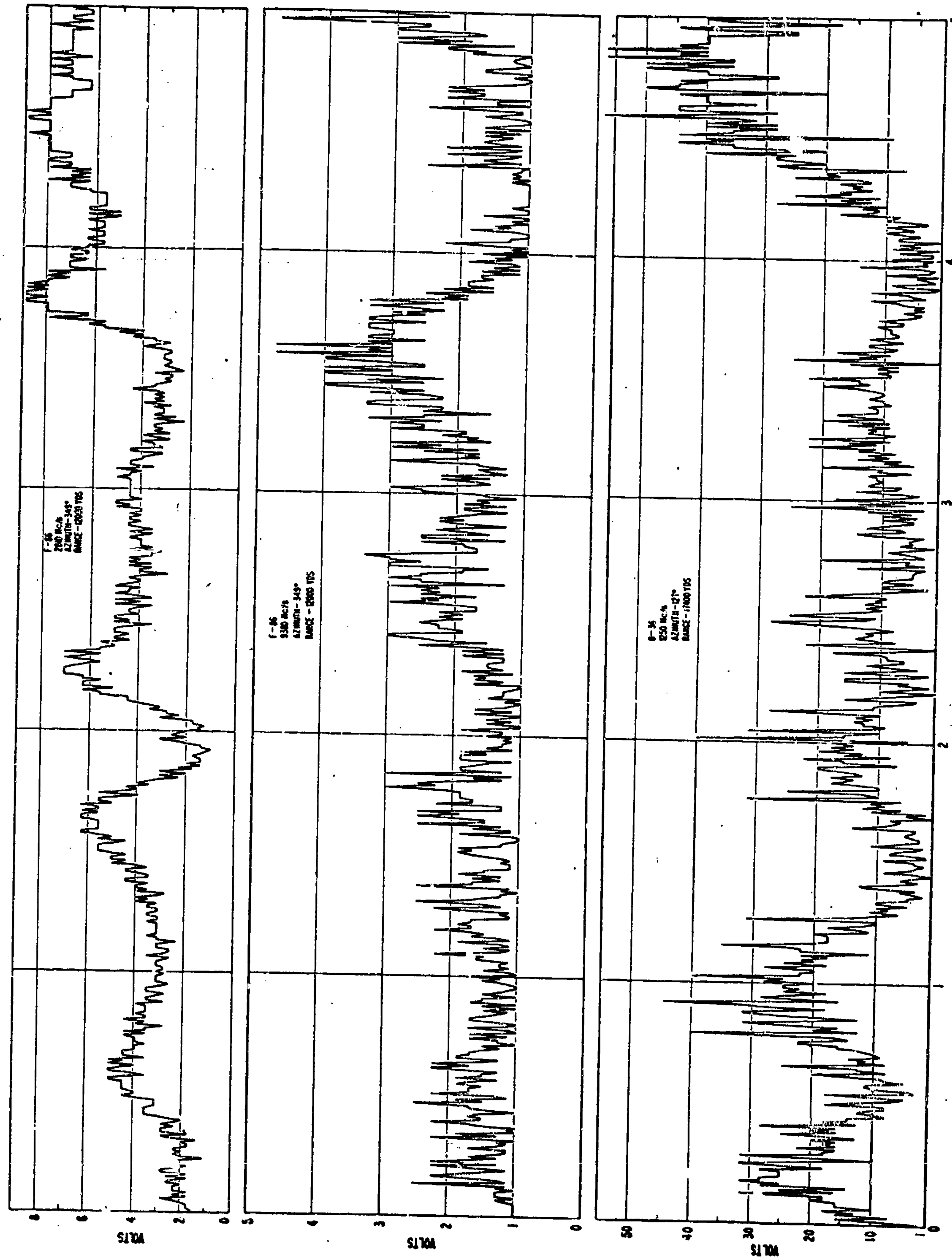

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Figure 1

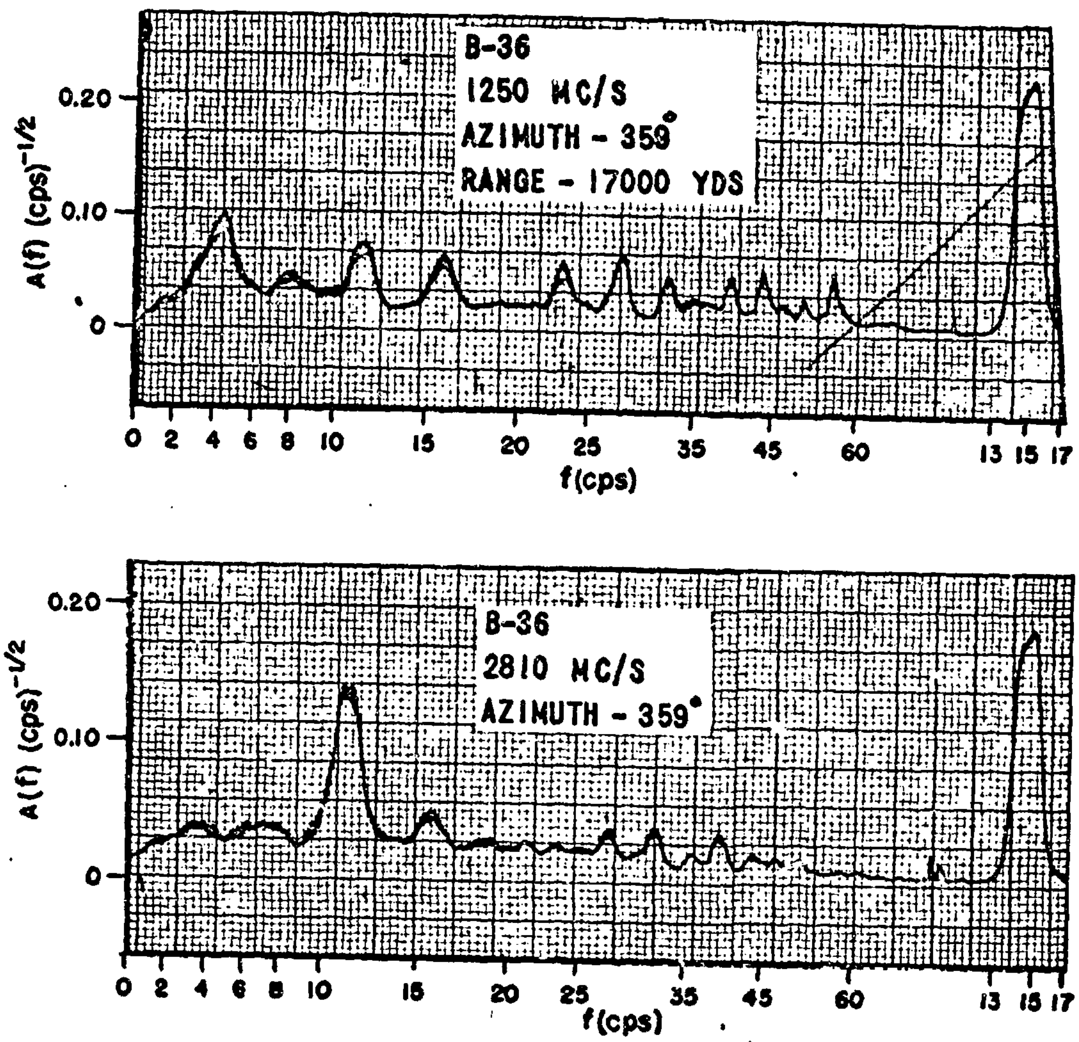

B-36
1250 MC/S
AZIMUTH - 359°
RANGE - 17000 YDS
A(f) (cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 35 45 60 13 15 17
f(cps)
B-36
2810 MC/S
AZIMUTH - 359°
A(f) (cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 35 45 60 13 15 17
f(cps)

Figure 2

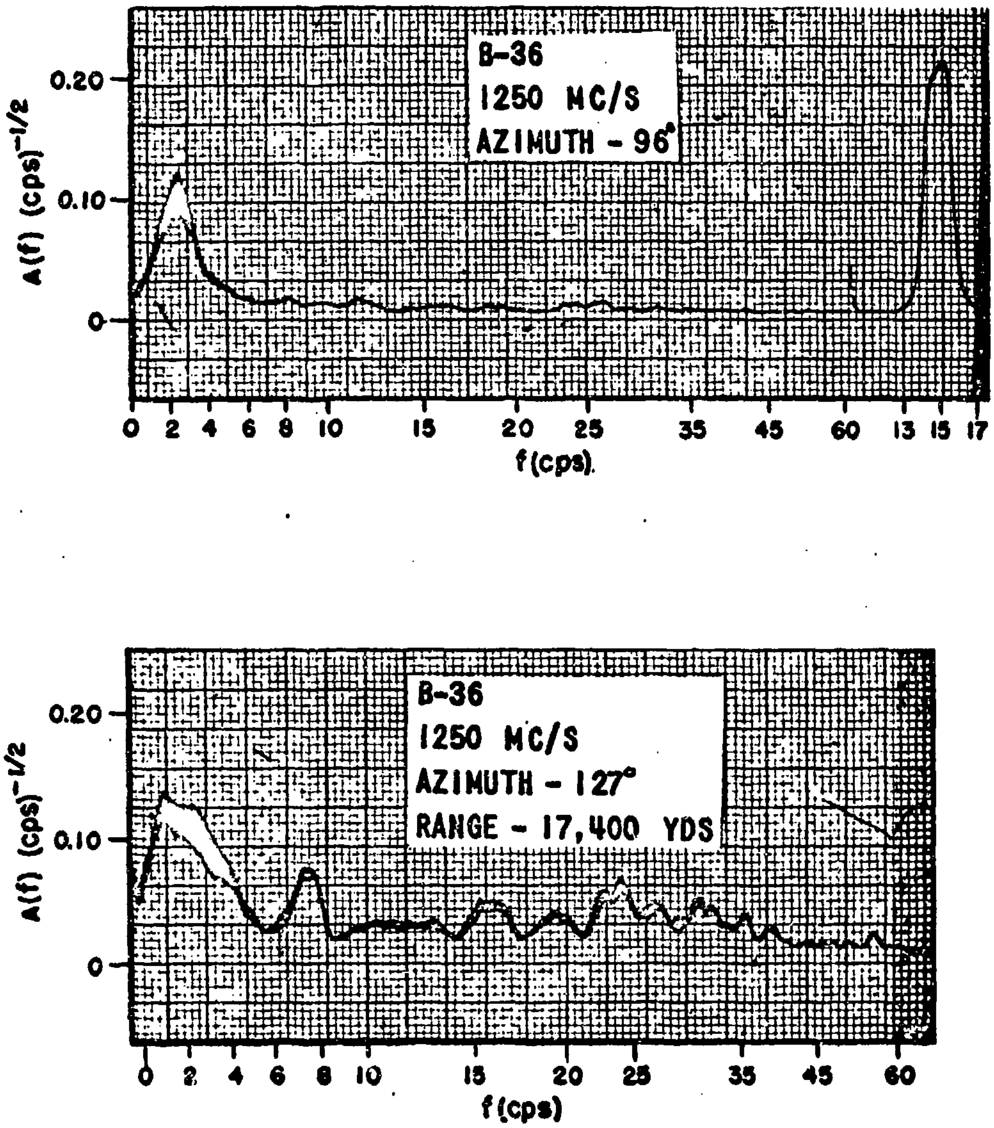

B-36
1250 MC/S
AZIMUTH - 96°
0.20
0.10
0
A(f) (cps)^-1/2
0 2 4 6 8 10 15 20 25 35 45 60 13 15 17
f(cps)
B-36
1250 MC/S
AZIMUTH - 127°
RANGE - 17,400 YDS
0.20
0.10
0
A(f) (cps)^-1/2
0 2 4 6 8 10 15 20 25 35 45 60
f(cps)

Figure 3

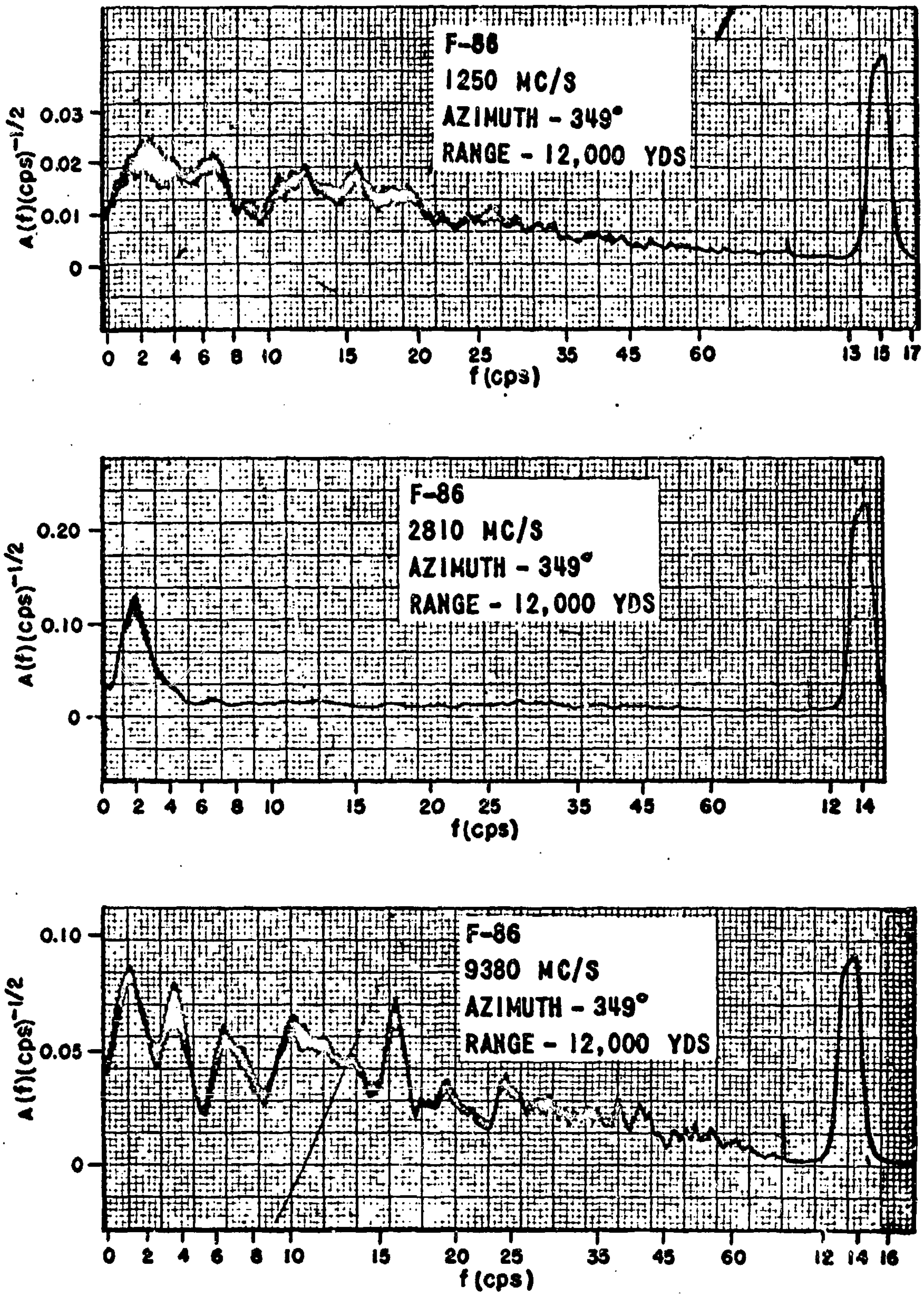
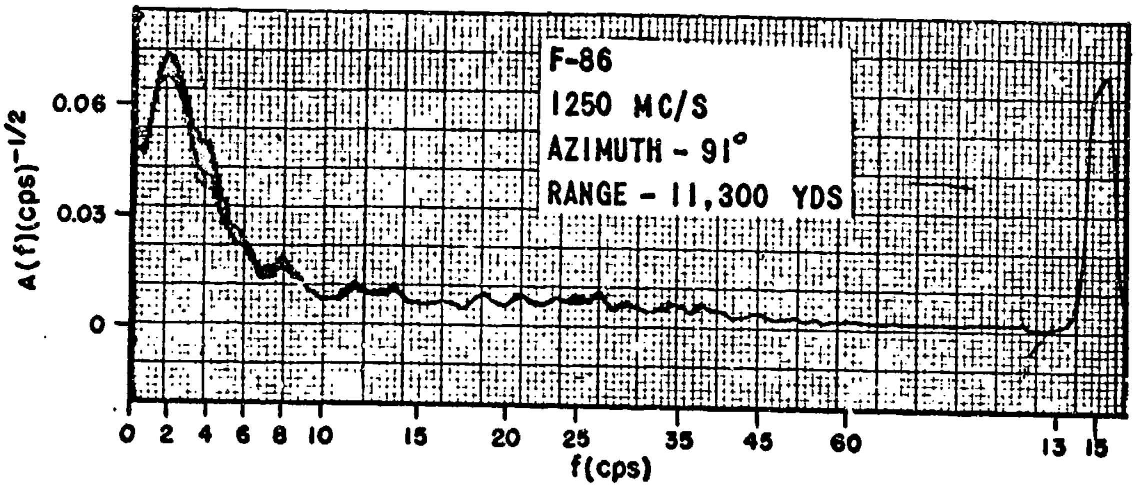
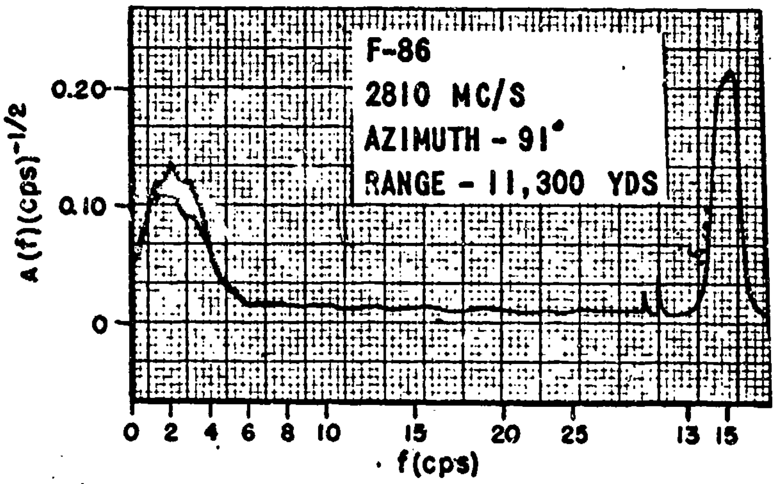

F-86
1250 MC/S
AZIMUTH - 349°
RANGE - 12,000 YDS
A(f)(cps)^-1/2
0.03
0.02
0.01
0
0 2 4 6 8 10 15 20 25 35 45 60 13 15 17
f(cps)
F-86
2810 MC/S
AZIMUTH - 349°
RANGE - 12,000 YDS
A(f)(cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14
f(cps)
F-86
9380 MC/S
AZIMUTH - 349°
RANGE - 12,000 YDS
A(f)(cps)^-1/2
0.10
0.05
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14 16
f(cps)

Figure 4


F-86
1250 MC/S
AZIMUTH - 91°
RANGE - 11,300 YDS
A(f)(cps)^-1/2
0.06
0.03
0
0 2 4 6 8 10 15 20 25 35 45 60 13 15
f(cps)


F-86
2810 MC/S
AZIMUTH - 91°
RANGE - 11,300 YDS
A(f)(cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 13 15
f(cps)

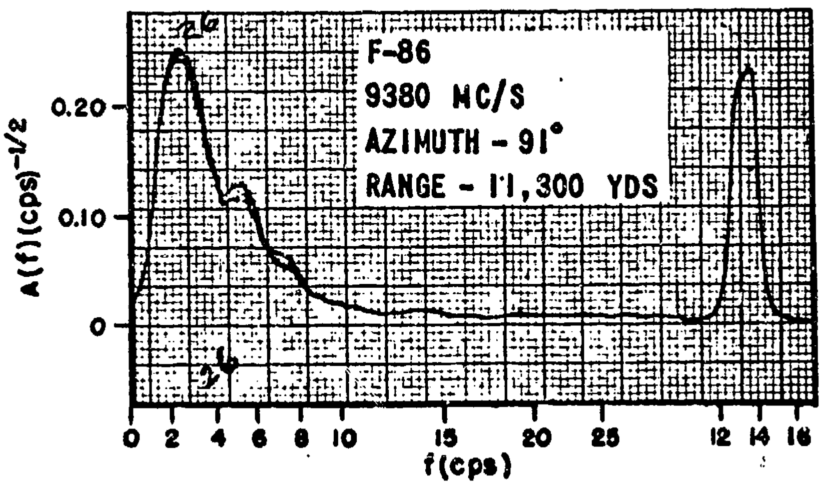

F-86
9380 MC/S
AZIMUTH - 91°
RANGE - 11,300 YDS
A(f)(cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 12 14 16
f(cps)

Figure 5

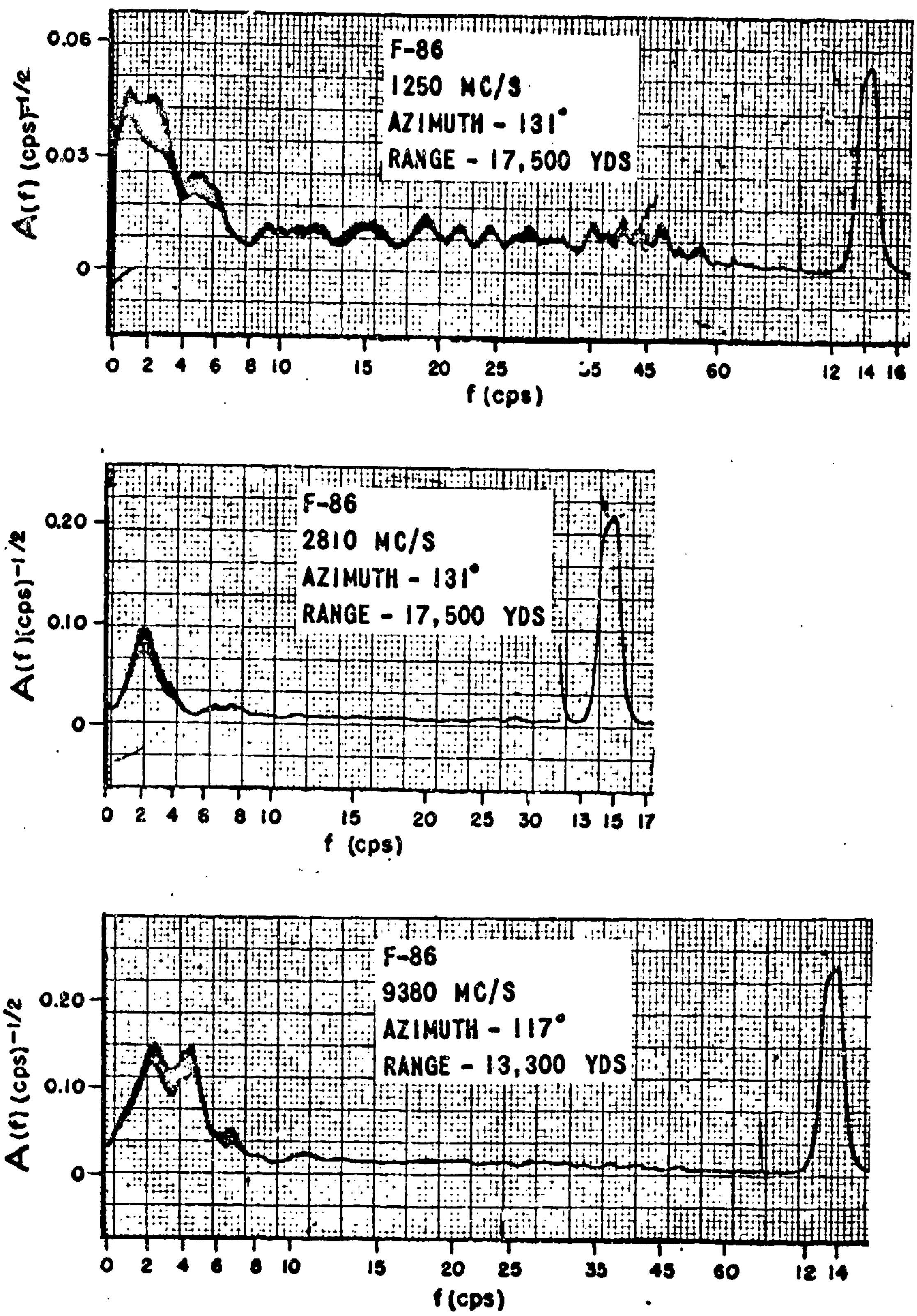
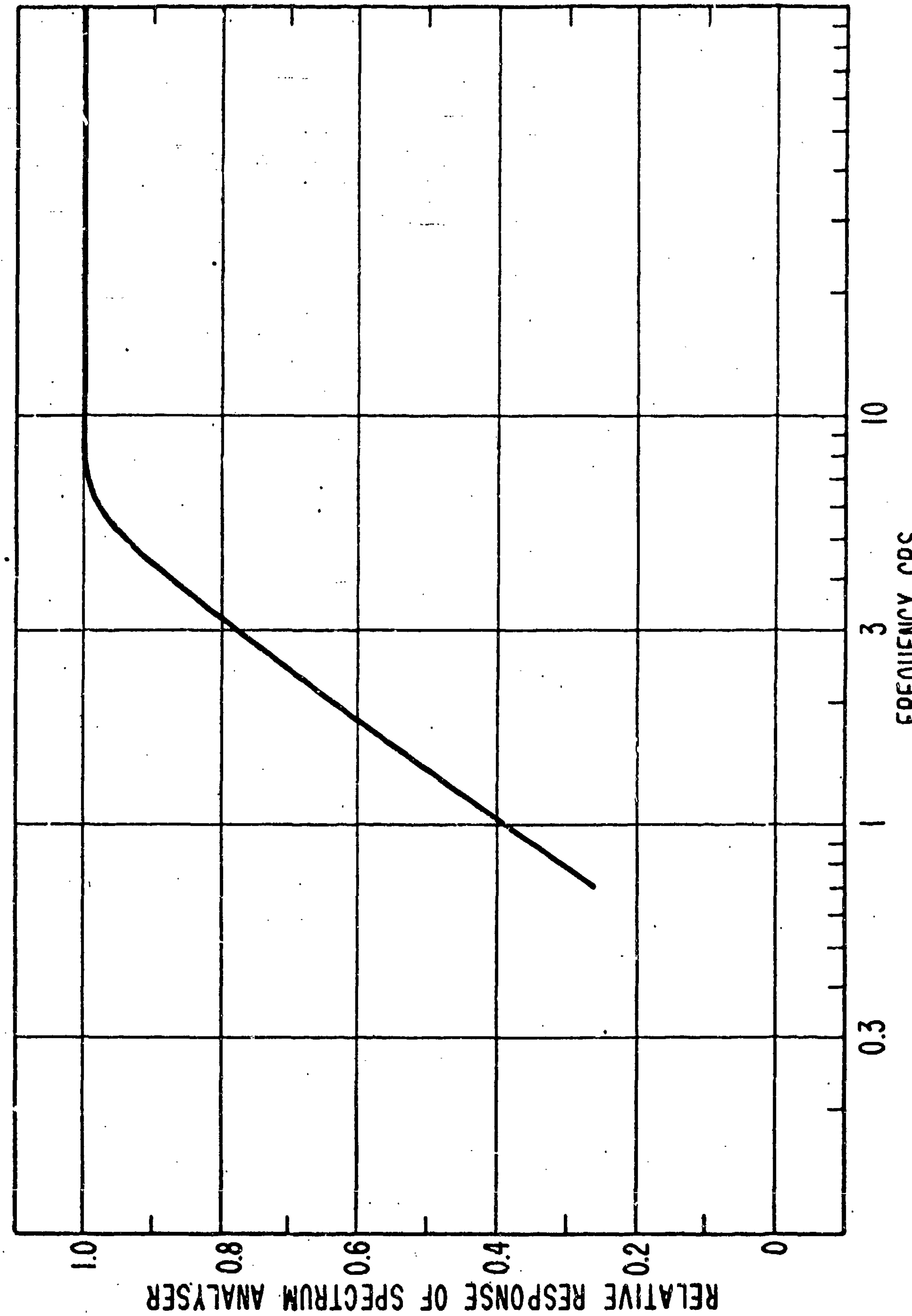

F-86
1250 MC/S
AZIMUTH - 131°
RANGE - 17,500 YDS
A(f) (cps)^-1/2
0.06
0.03
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14 16
f (cps)
F-86
2810 MC/S
AZIMUTH - 131°
RANGE - 17,500 YDS
A(f) (cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 30 13 15 17
f (cps)
F-86
9380 MC/S
AZIMUTH - 117°
RANGE - 13,300 YDS
A(f) (cps)^-1/2
0.20
0.10
0
0 2 4 6 8 10 15 20 25 35 45 60 12 14
f (cps)

Figure 6



1.0
0.8
0.6
0.4
0.2
0
RELATIVE RESPONSE OF SPECTRUM ANALYSER
0.3
1
3
10
FREQUENCY CPS

Figure 7